

Spectral softening due to winds in accretion disks

Sandip K Chakrabarti

S. N. Bose National Centre for Basic Sciences,
JD-Block, Sector-III, Salt Lake, Calcutta 700 091, India

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Abstract . Accretion flows may produce profuse winds when they have positive specific energy. Winds deplete matter from the inner region of the disk and makes the inner region thinner, optically. Since there are fewer electrons in this region, it becomes easier to Comptonize this part by the soft photons which are intercepted from the Keplerian disk farther out. We present a self-consistent picture of winds from an accretion disk and show how the spectra of the disk is softened due to the outflowing winds.

Keywords → Astrophysical black holes, accretion and outflows, spectral properties

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Outflows are common in many astrophysical systems which contain black holes and neutron stars. Difference between stellar outflows and outflows from these systems is that the outflows in these systems have to form out of the inflowing material only, whereas in stars outflows originate from the stellar atmosphere. Although a black hole does not have a hard surface, the centrifugal barrier due to angular momentum behaves like one, and therefore mass loss associated with this barrier could be computed in the same way as the mass loss from a stellar surface. For a detailed review on accretion disks and associated outflow, see Chakrabarti [1,2].

Chakrabarti [3] classified all possible solutions of a black hole accretion and winds and showed that a large region of the parameter space (spanned by specific energy ϵ and angular momentum λ) with positive ϵ , winds would form. Such solutions (both accretion and winds) have been amply verified by numerical simulations [4]. Winds have been observed by earlier numerical simulations from Keplerian accretion disks [5], although generalized self similar wind solution of Königl [6] by Chakrabarti and Bhaskaran [7] show that the outflows are more favourable if the disk itself is sub-Keplerian. Chakrabarti and D'silva [8] and D'silva and Chakrabarti [9] showed that magnetized flares close to the funnel wall in the accretion disk could produce winds similar to that of the Sun. This is because, energetically, it is equally easy or difficult for an ordinary star or compact object to produce winds. Molteni, Lanzafame and Chakrabarti [10] showed through numerical simulation that up to about 15 to 20 percent of mass loss is common in the case of weakly viscous, and thick accretion flows. Chakrabarti [11]

viscosity region, namely on the equatorial plane. The low viscosity region away from the plane has positive specific energy and forms an advective inflow which may or may not form a shock wave closer to the centrifugal barrier. Keplerian disks emit soft blackbody photons which are intercepted and reprocessed in CENBOL and its surrounding sub-Keplerian region. Radiation out of this region through Comptonization and bremsstrahlung processes come out carrying the information about the optical depth and temperature of this region. Thus a proper prediction of the power-law spectra in hard X-rays would be valuable to understand black hole accretion and wind processes.

Figures 2 and 3 show the outcome of our calculation of the spectra for different accretion rate of the Keplerian component \dot{M}_m . The mass of the central black hole is chosen to be $M = 10 M_\odot$. The location of the CENBOL is assumed to be at $r = 10 r_g$ (where r_g is the Schwarzschild radius), a typical location for the sub-Keplerian flow of average specific angular momentum $\lambda = 1.75$ and specific energy $\epsilon = 0.003$. Following [12], we first compute the mass outflow rate from the advective region. The long dashed curve in Figure 2 shows the variation of the percentage of mass loss (vertical axis on the right) as a function of the inflow accretion rate. The dotted curve and the solid curve denote the variation of the energy spectral index α ($F_\nu \propto \nu^{-\alpha}$) with and without winds taken into account. Note that the spectra is overall softened (α increased) when winds are present. For higher Keplerian rates, the mass loss through winds is negligible and therefore there is virtually no change in the spectral index. For lower inflow rates, on the other hand, mass loss rate is more than twenty percent. It is easier to Comptonize the depleted matter by the same number of incoming soft photons and therefore the spectra is softened.

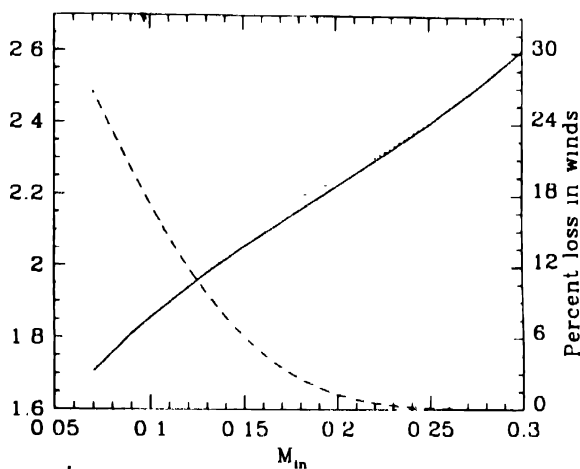


Figure 2 Variation of the percentage of mass loss (long dashed curve and right axis) and the energy spectral index α ($F_\nu \propto \nu^{-\alpha}$) (solid and dotted curves and left axis) with the accretion rate (in units of Eddington rate) of the Keplerian component. Solid curve is drawn when winds are neglected from the advective region and dotted curve includes effect of winds. Overall spectra is softened when the inflow rate is reduced.

In Figure 3, we show the resulting spectral change. As in Figure 2, solid curves represent solutions without winds and the dotted curves represent solutions with winds. Solid curves are drawn for $\dot{M}_m = 0.3$ (uppermost at the bump), 0.15 (middle at the bump) and 0.07 (lowermost at the bump) respectively. For $\dot{M}_m = 0.3$ both curves are identical. Note the crossing of the

solid curves at around $10^{18.6}$ Hz (15 keV) when winds are absent. This is regularly observed in black hole candidates. If this is shifted to higher energies, the presence of winds may be indicated.

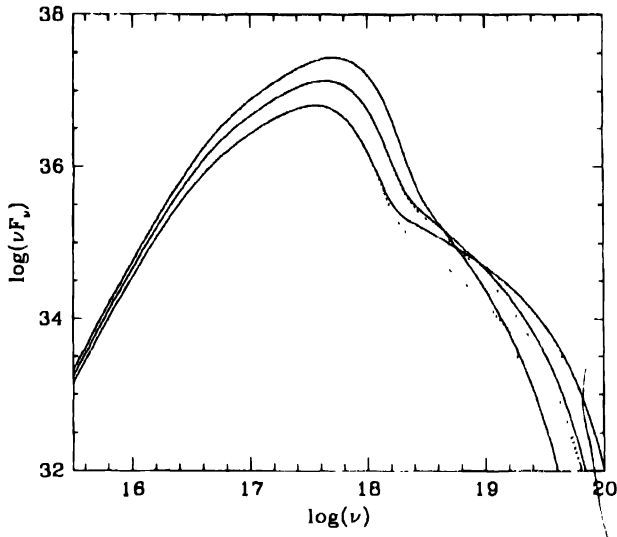


Figure 3 Spectra of emitted radiation from the accretion disk with (dotted) and without (solid) effects of winds. Hard X-ray component is softened while keeping soft X-ray bump unchanged.

Strong winds are suspected to be present in Sgr A* at our Galactic Center (see, Genzel *et al* [15] for a review, and Eckart and Genzel [16]). Chakrabarti [1] suggested that the inflow could be of almost constant energy transonic flow, so that the emission is inefficient. However, from global inflow-outflow solutions [GIOS], Das and Chakrabarti [12] showed that when the inflow rate itself is low (as is the case for Sgr A*; $\sim 10^{-5}$ to $10^{-4} M_{\text{Eddington}}$) the mass outflow rate is very high, almost to the point of evacuating the disk. This prompted them to speculate that spectral properties of our Galactic Center could be explained by inclusion of winds. This will be done in near future. Not only our Galactic Center, the consideration should be valid for all the Black hole candidates (e.g. V404 Cyg) which are seen in quiescence.

Earlier, Chakrabarti and Titarchuk [13] suggested that the iron K_{α} line as well as the so called 'reflection component' could be due to outflows off the advective region. Combined with the present work, we may conclude that simultaneous enhancement of the 'reflection component' and/or iron K_{α} line intensity with the softening of the spectra in hard X-rays would be a sure signature of the presence of significant winds in the advective region of the disk.

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